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IMPACTS OF STRATEGIC GRAZING AND FIRE ON SOIL SEED BANK HETEROGENEITY IN MIXED-GRASS PRAIRIE

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ABSTRACT

Native plant communities in the Northern Great Plains evolved under periodic fire and substantial grazing pressure from native herbivores, two main drivers maintaining the heterogeneity of grassland ecosystems. However, contemporary management practices focus on maximizing livestock production through fire suppression and uniform grazing strategies, resulting in decreased vegetation heterogeneity, species richness, wildlife habitat, and biodiversity. Objectives of this study were to evaluate and compare the effectiveness of patch-burn grazing (PBG) and winter-patch grazing (WPG) managements on soil seed bank heterogeneity in terms of species 1) richness, 2) composition, 3) abundance, and 4) diversity. Two soil cores (10-cm dia × 10-cm depth) were extracted and composited from each of five exclosures on PBG, WPG and conventional grazing (control) patches (CG) in each of 3 pastures for a total of 45 composite soil cores. Samples were passed through a 2 mm sieve into flats and maintained in a greenhouse. For 3 months, emerged seedlings were recorded and identified. Overall, 2006 seedlings among 54 species emerged within CG (855 seedlings, 42 species), WPG (674 seedlings, 42 species), and PBG (477 seedlings, 31 species). Most seedlings were annual, native forbs. Kentucky bluegrass (*Poa pratensis*) was most abundant in CG (20%), 10% in WPG, and 2% in PBG. Species richness, composition, abundance, and diversity for PBG treatments were significantly lower than for CG and WPG treatments. Our findings suggest that PBG has a negative impact on seed bank species richness, composition, abundance, and diversity compared to WPG and CG. This study suggests that WPG may provide greater potential for seed bank richness, composition, abundance, and diversity than burning while also serving as a more palatable management tool for managers who are averse to fire.

Keywords

Winter-patch grazing, patch-burn grazing, biodiversity, abundance, species richness, species composition

INTRODUCTION

Native plant communities in the Northern Great Plains (NGP) evolved under periodic fire and substantial grazing pressure from native herbivores (Knapp et al. 1999). Northern Great Plains grasslands contain critical habitat for a variety of wildlife species and are an important breeding ground for 330 of the 435 bird species of the United States (Stephens et al. 2008). Unfortunately, these habitats are diminishing. Approximately 70-90% of NGP mixed-grass prairies have vanished, while only 1% of original tall-grass prairies remain (Samson and Knopf 1994). Fragmentation due to croplands has disrupted the remaining native grasslands (Samson and Knopf 1994). Invasive cool-season perennial grasses such as Kentucky bluegrass (*Poa pratensis* L.) and smooth brome (*Bromus inermis* Leyss.) have also disrupted the NGP prairies and are becoming an increasingly common sight (Murphy and Grant 2005). The resilience of prairie ecosystems and diversity of native plant communities are threatened by these invasive, exotic species (DeKeyser et al. 2015; Toledo et al. 2014). Using and understanding the impacts of different management practices such as fire and grazing will help land owners and managers to reduce invasive species and promote heterogeneity within the prairies.

Grassland habitats in the NGP have become homogenized due to bison and its interaction with fire being replaced by moderate livestock grazing (Scasta et al. 2016). Management for heterogeneity through manipulation of fire and cattle grazing is uncommon. Historically, bison grazing and distribution patterns were driven by frequent, low-intensity fires, the restoration of which could similarly alter cattle herbivory (Allred et al. 2011a, b). Modern manipulation of grazing behavior involves fencing and altering feeding locations or water distribution to focus cattle in specific areas. While these are effective tools, they cannot replicate the effects on vegetation structure of strategically applied fires and resulting bison grazing behavior (Machicote et al. 2004; Towne et al. 2005). The historic interaction between fire and grazing has been mimicked by the management practice of patch-burn grazing (PBG), which consists of burning discrete patches within pastures and allowing cattle to select where they graze (Scasta et al. 2016). This application of patch-burn grazing was developed as a restorative framework to recouple grazing and fire interactions as an ecological process that maintained grassland diversity in North America (Fuhlendorf and Engle 2001; 2004). Research results indicate that the interactive effects of patch burning and strategic livestock grazing can increase heterogeneity by creating a mosaic of vegetation use levels across a landscape (Fuhlendorf et al. 2006). Fire is not, however, a universally accepted management strategy. Many landowners and managers exhibit an aversion to burning due to concerns of safety, liability, and forage losses (Toledo et al. 2014). Derner et al. (2009) demonstrated the value of using livestock as ecosystem engineers and encouraged experimental evaluation of livestock grazing for development of heterogeneity on NGP rangelands. Studies were initiated at the SDSU Cottonwood Station several years ago to evaluate the use of heavy winter grazing as an alternative to burning for promoting heterogeneity. The goal was to determine whether winter-patch grazing (WPG) could provide benefits similar to those associated with PBG. With WPG, discrete patches within a pasture are heavily grazed during the non-growing season to reduce standing vegetation height to about 5 cm, then cattle are allowed to select where they graze during the following growing season.

Previous and on-going studies of PBG and WPG focus largely on plant community diversity, structural diversity, livestock production, and habitat for wildlife. Very little emphasis has been focused on another important component of these prairie ecosystems that greatly impacts restoration: soil seed banks. Seed banks are a memory of the plant communities that once inhabited a given section of land and are full of dormant seeds waiting to emerge when given the opportunity (Bakker et al. 1996). One study found that a successfully retrieved seed bank contained 133 species that accounted for 80% of the 166 species at the study site (Sternberg et al. 2009). Sternberg et al. (2009) also found that seed bank densities varied between grazing practices and years, with continuous and heavy grazing reducing the seed bank densities of grasses when compared to moderate grazing. The opportunity to retrieve plants that are present in seed banks via management practices could have a positive effect on plant diversity and heterogeneity in pastures and prairies. The diversity of plants available would allow more animal and plant species to persist, leading to a healthier ecosystem.

The objective of this study is to gain greater insight into the effect of management practices on soil seed banks by evaluating and comparing patch-burn grazing, winter-patch grazing, and conventional summer grazing (CG) in mixed-grass prairie on soil seed bank heterogeneity in terms of species 1) richness, 2) composition, 3) abundance, and 4) diversity. There is no known literature on the effects of winter-patch grazing on seed banks; thus, this study should help fill that gap. Since WPG and PBG managements create different environmental conditions during and after disturbances, we hypothesized that patch-burn grazing and winter-patch grazing will differ from each other and CG in their impacts on species richness, composition, abundance, and diversity of seed banks in the years post-disturbance.

METHODS

Study Site. This study was conducted at the Cottonwood Range and Livestock Research Station located in western South Dakota (Lat. 43° 55’08” N, Long. 101° 52’58” W) (Smart et al. 2007) (Figure 1). The climate is continental and semiarid with hot summers and cold winters. Long-term mean annual precipitation (1922 to 2016) is 412-mm, 76% of which falls from April to September. Mean annual temperature is 8 °C with a low of -6.8 °C in January and a high of 24 °C in July (https://w2.weather.gov/climate/xmacis.php?wfo=unr). Remnant native mixed-grass prairie vegetation is dominated by a variety of species such as western wheatgrass (*Pascopyrum smithii* (Rydb.) Á. Löve), blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths), and buffalograss (*Bouteloua dactyloides* (Nutt.) Engelm.). Major land use is cattle grazing. Large areas of several pastures were burned in a wildfire that occurred on October 6, 2016 (Figure 2).

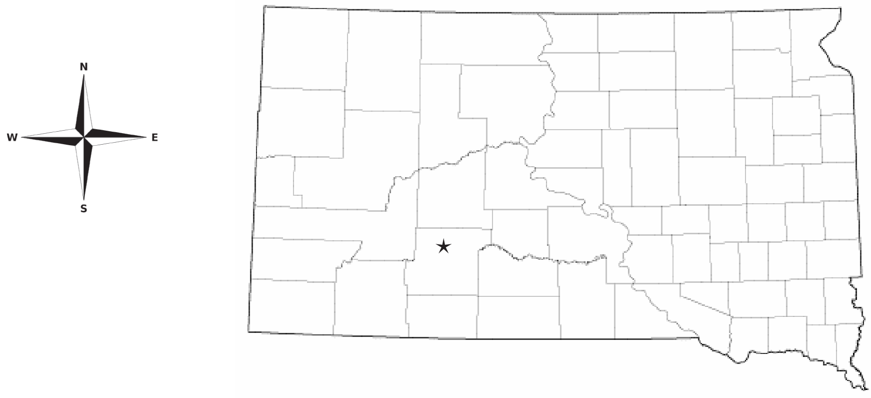

Figure 1. Location of Cottonwood Range and Livestock Research Station in Jackson County in western South Dakota.

Experimental Design and Treatments. The experiment was a randomized block design with three treatments and three blocks. The treatments were patch-burn grazing (PBG), winter-patch grazing (WPG), and conventional summer grazing (CG) as a control. The three pastures (pastures 3, 5, and 6) were the blocks, and each pasture contained all three treatments (Figure 2). Five exclosures (4.8-m × 4.8-m) of similar soil type were randomly located within each treatment in each pasture, resulting in 15 exclosures/pasture and 45 exclosures total. Soil seed bank samples were taken from within the exclosures.

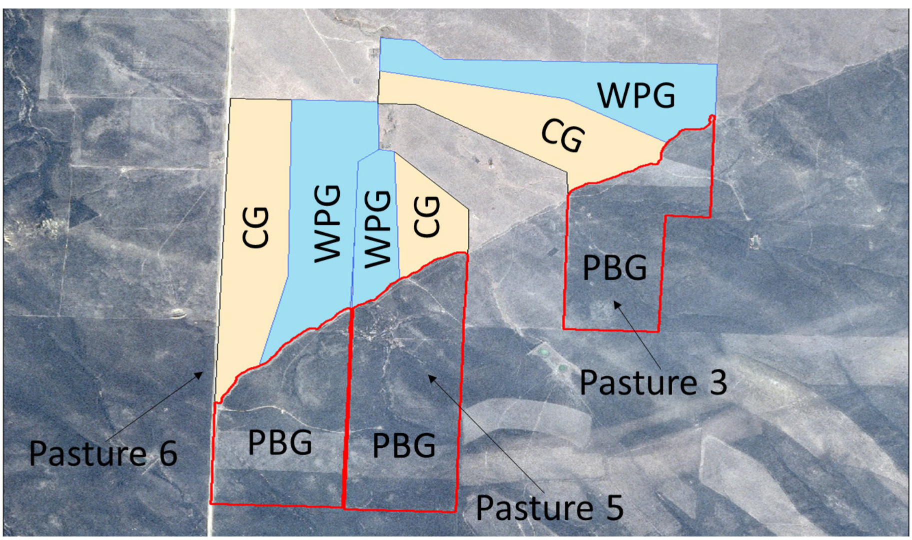

Figure 2. Layout of treatments and pastures at the Cottonwood Research Station. A wildfire burned a large area of the station in October 2016, including the southern areas of pastures 3, 5, and 6. Those three pastures served as replicates in the study. Each pasture was divided into 3 areas: PBG = Patch-burn grazed; WPG = Winter-patch grazed; CG = Control, no burn, no winter graze.

Sampling Procedure and Data Collection. In October 2017, two soil cores (10-cm dia. × 10-cm depth) were removed from randomly selected locations and composited in each of the 5 exclosures in each treatment in each pasture, resulting in 90 cores and 45 composite samples. Each of the samples was passed through a 2-mm sieve into a 25-cm × 25-cm seed flat. The flats of soil core material were maintained in an environmentally controlled greenhouse with a 16-hr light/8-hr dark photoperiod and 23 ± 2 °C temperature. Seed flats were watered daily, and seedlings were identified and counted as they emerged, then removed weekly for three months. Unidentifiable seedlings were transplanted and allowed to grow until identification could be made (Figure 3).

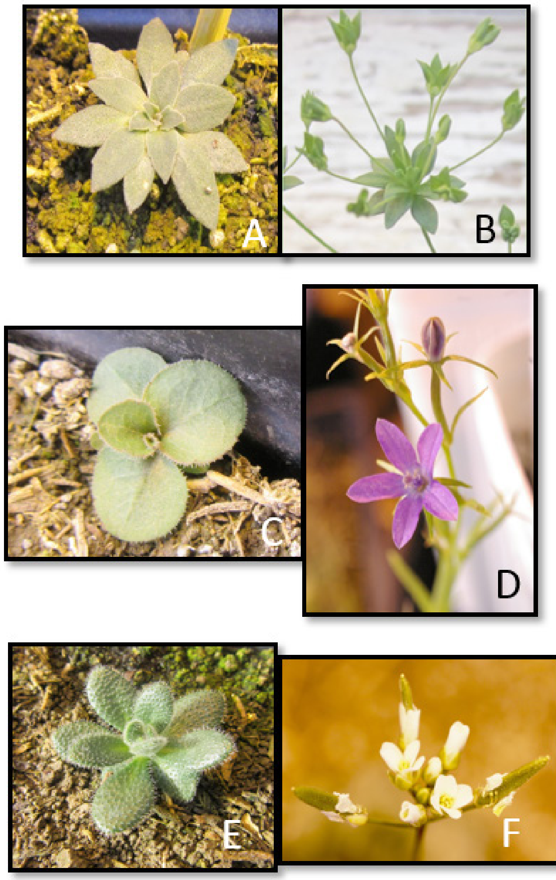

Figure 3. Photographs of some seedlings that were allowed to develop to maturity so that identification was possible. Species include: Androsace occidentalis (A = seedling, B = mature seed-head), Triodanis lepocarpa (C = seedling, D = mature plant with flowers), and Draba reptans (E = seedling, F = mature plant with flowers and seed pods).

Data Analysis. A one-way ANOVA analysis was conducted for all response variables; comparisons were significant if $P < 0.05$.

Jaccard's Similarity Index was calculated for all treatment pairwise comparisons.

$$\text{Jaccard} = \frac{S_{ab}}{S_a + S_b + S_{ab}} \qquad \text{(Equation 1)}$$

where S_{ab} is the number of species common to both communities being compared, S_a is the number of species found only in community A, and S_b is the number of species found only in community B. Values of the index range from 0 to 1. A value of 1 indicates that the species of the two communities are identical. A value of 0 indicates that the two communities are entirely dissimilar and have no species in common. (Magurran 1988).

The Shannon-Weiner Diversity Index was calculated using

$$H' = -\sum_{i=1}^{S} p_i \ln p_i \qquad \text{(Equation 2)}$$

where p_i is the proportion of individuals of the i^{th} species (calculated as n_i/N, where n_i is the number of individuals of species i and N is the total number of individuals of all species); ln p_i is the natural logarithm of p_i; and S is species richness (i.e. total number of different species (Magurran 1988).

Rank-abundance curves were constructed for each treatment to portray diversity. For each treatment, the number of species and their abundance were combined from all three pastures. Within each treatment, species were plotted in sequence from most to least abundant along the x-axis. Their relative abundance was displayed in a $\log_{10}$ format on the y-axis (Magurran 1988).

RESULTS

Species Richness. Total mean species richness in PBG was significantly different from CG and WGP ($P < 0.0001$), while there was no significant difference between CG and WPG. PBG treatment resulted in the lowest total species richness at 7 species compared to CG and WPG treatments at 11 and 12 species, respectively (Figure 4).

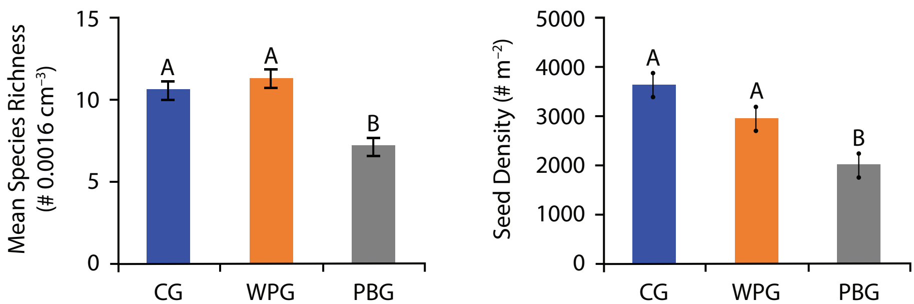

Figure 4. Total mean species richness (left) and density (right) of seeds among control (CG), winter-patch grazed (WPG), and patch-burn grazed (PBG) treatments. Different letters above bars within a graph indicate significant differences among treatments (P < 0.05). Standard error bars are displayed for each treatment bar.

Species Composition. A total of 2006 seedlings emerged, representing 18 families, 47 genera, and 54 species. The families containing the most species included Poaceae (22.22%), Brassicaceae (18.52%), Asteraceae (12.96%), and Fabaceae (11.11%). These four families accounted for 65% of the total species. A total of 855 seedlings representing 42 species, 40 genera, and 17 families emerged from CG, 674 seedlings comprising 42 species, 40 genera, and 15 families from WPG, and 477 seedlings belonging to 31 species, 30 genera, and 13 families from PBG.

The majority of the species that emerged from all three treatments consisted of annuals (60 - 68%), natives (67 - 85%), and forbs (74 - 89%) (Figure 5A). Functional groups of emerged seedlings were dominated by annual native forbs ranging from 58% in CG, 60% in WPG to 85% in PBG. The treatments had a significant effect ($P < 0.05$) on the number of emerged species of annuals, perennials, forbs, graminoids, native and introduced species. Among the three treatments, PBG had the lowest number for all six parameters; there was no difference between WPC and CG, except for graminoids, where WPG had a significantly higher number than CG. PBG had the fewest graminoids (Figure 5A).

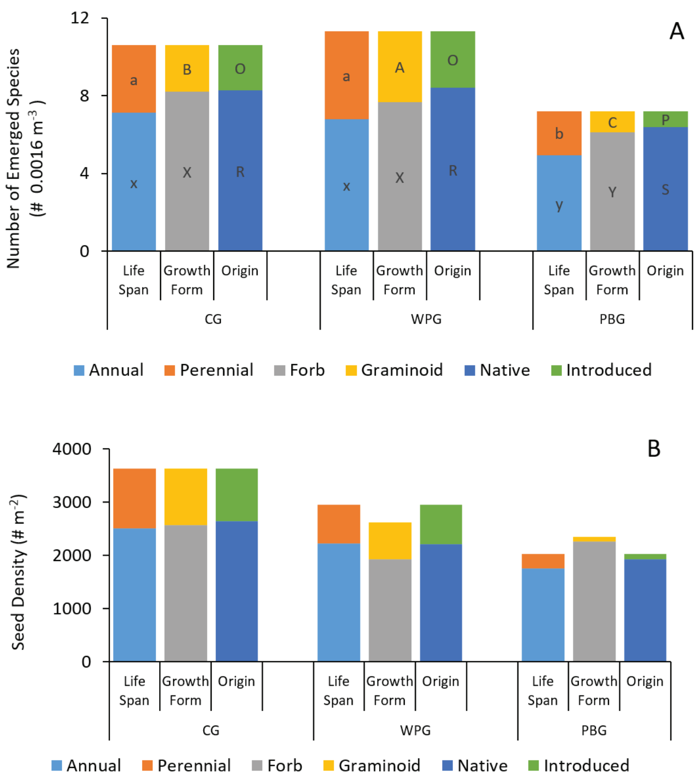

Figure 5. Comparison of plant life span, growth form, and origin among treatments (CG = control; WPG = winter-patch grazed; PBG = patch-burn grazed) for A) emerged species and B) seed density. Samples for number of emerged species are based on two combined soil cores (each 10 cm diam. × 10 cm depth). Means with different letters within same life span, growth form or origin were significantly different (P < 0.05).

Species Abundance. The most abundant species was *Androsace occidentalis* (Pursh) (Figure 3A-B), which represented 26.7% of total emerged seedlings in CG, 28% in WPG, and 44.5% in PBG. The most abundant graminoid species was *Poa pratensis* (20% in CG, 10% in WPG, and 2% in PBG, respectively). Other abundant species include *Triodanis lepocarpa* (Nutt.) Nieuwl. (Figure 3C-D), and *Draba reptans* (Lam.) Fernald (Figure 3E-F). PBG treatment had significantly lower seed density (2,025 seeds/) than CG treatment (3,631 seeds/) and WPG treatment (2,951 seeds/m^2) (P = 0.001) (Figure 4B).

Species Diversity. Rank-abundance curves indicate that species evenness was more similar between CG and WPG compared to PBG (Figure 6). Shannon's measure of evenness showed no difference among the treatments. However, Shannon's measure of diversity showed PBG was dominated by 3 species (contributing to 70% relative abundance) and had lower diversity compared to CG and WPG. There was no difference between CG and WPG treatments for diversity (Figure 6). Jaccard's Index Similarity values for the treatment pairwise comparisons were between 55% to 58%.

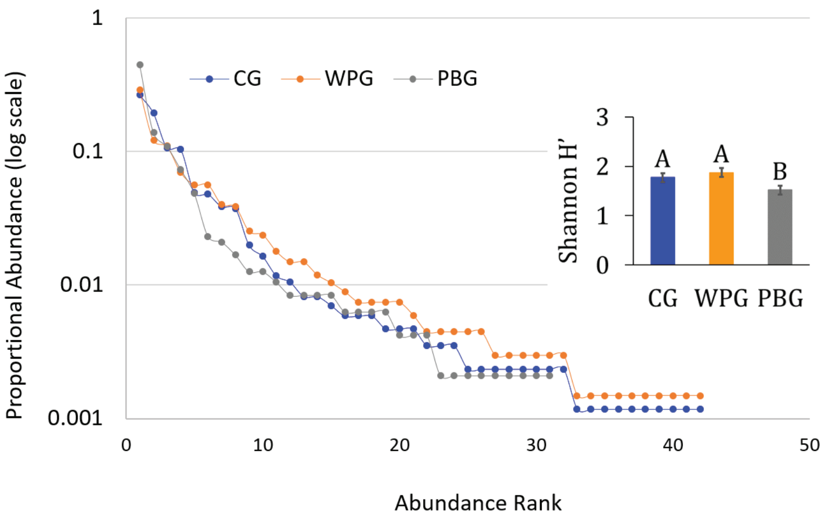

Figure 6. Rank-abundance curves of seed bank for CG, WPG, and PBG treatments with a bar chart overlay of Shannon-Weiner Diversity Index results. Different letters above bars within the diversity graph indicate significant differences among treatments (P < 0.05). Standard error bars are displayed for each treatment bar.

DISCUSSION

Soil seed banks of plant communities represent the "memory" of previous conditions (Templeton and Levin 1979) and are an important component of the potential of the community to respond to environmental conditions in the present and future (Coffin and Lauenroth 1989). Seed banks play a critical role in the composition and structure of existing vegetation, restoring native vegetation, creating habitat for wildlife, preserving genetic diversity and recovering endangered plant species.

It is reasonable to assume that seed banks and the resulting plant communities can be affected by grazing management and fire (Lei and Bai 2017; Metzger et al. 2005; Sternberg et al. 2009; Tessema et al. 2016). Our findings demonstrate, however, that the winter-patch grazing treatment did not affect the soil seed bank. There were no differences between winter-patch grazing and conventional summer grazing for species richness, abundance, diversity or composition, in terms of life span, growth form, and origin. This indicates that heavy grazing during the non-growing season for the purpose of reducing standing vegetation height to create structural heterogeneity had no influence on soil seed bank compared to conventional summer grazing. Conversely, our study also shows that species richness, composition, abundance, and diversity of the seed bank were significantly reduced by patch-burn grazing compared to conventional grazing. This suggests that fire, which is very useful in altering vegetation structure, may result in an undesirable limitation of future aboveground species richness, composition and diversity.

Both the heavy winter grazing and the fire occurred during the non-growing season when plants were in physiological dormancy. Winter grazing occurred well after the seed-set stages that Sternberg et al. (2009) found had the greatest negative impact on seed bank density. Winter grazing removed only standing dead biomass, with little or no effect on perennating plant structures. Seeds still attached to the aboveground plant structures would have been either consumed as part of the forage or knocked off into the litter or onto the soil. The litter layer protecting seeds from winter winds and cold was intact. Fire, however, burned all standing dead and litter, and likely damaged plant crowns. Nearly 100% of aboveground vegetation was burned; islands of unburned vegetation that could provide seed sources were rare on the landscape. Seeds on aboveground plant structures and in the litter were burned, and the high temperatures associated with the fire likely destroyed some of the seeds at or below the soil surface. There was no litter to provide cold and wind protection for viable seeds in or on the soil in burned areas during winter.

It is important to note that no two disturbances create equal environments, even when the disturbances are very similar. The outcome of two fires, for example, may differ dramatically depending on numerous factors, including timing, fuel load, and fire intensity. The fire in our study occurred in a very dry October as a wildfire (not typical for PBG practices). The fire was hot, burning all of the aboveground plant material, including litter, and leaving extensive bare soil between singed plant crowns. Fires that occur in other seasons and/or under other conditions that burn cooler or in a patchier pattern may well yield different results with regard to seed banks.

Timing of soil seed bank sampling may also have played a role in the seed bank results presented here. Data collection for this study occurred in October, one-year post fire. Some seeds remaining in the seed bank of each treatment may have germinated in the growing season after the treatments. Additional seed from plants growing in summer 2017 may have been added to the seed bank. I t is important to note that 2017 was an extremely dry year. In a separate study (Xu, unpublished data), we found aboveground production and species richness on the study site to be very limited. Thus, it is unlikely that the 2017 growing season substantially altered the seed bank sampled in October through germination or seed production. It is also important to note that the results of this study may only reflect a short-term consequence of WPG and PBG. Further study to evaluate the longer term effects of these treatments is needed.

The results from this study indicate that winter-patch grazing may serve as a better management tool than patch-burn grazing in conserving species compositional diversity in North American mixed-grass prairies. It appears from our study that patch-burn grazing, at least in the short-term, is probably more detrimental to seed banks. Certainly, alterations of the timing of grazing and burning may provide different outcomes. Variance in results from studies is expected and serves as a reminder that management practices are not a one-size-fits-all solution. Determining which management practice works best for a given location is the primary goal. Future research into this issue is required to better improve scientists' and land managers' understanding of how different management practices are impacting the Northern Great Plains mixed-grass prairies.

CONCLUSIONS

Structural and compositional heterogeneity of North American grassland ecosystems are driven primarily by fire and grazing. Fire suppression and uniform use of plant communities due to contemporary grassland management practices have decreased vegetation heterogeneity with corresponding reductions in species richness, wildlife habitat, and biodiversity. The results from this study support the proposed hypothesis that patch-burn grazing and winter-patch grazing have different impacts on species richness, composition, abundance, and diversity of seed banks one year post-disturbance. The findings suggest that patch-burn grazing (with the fire occurring in late fall) may have a negative impact on a seed bank compared to winter-patch grazing and conventional summer grazing. Patch-burn grazing appears to reduce perennials, graminoids, introduced species, and their seed reserves. In the end, winter-patch grazing may serve as a more palatable management tool than fire for land managers concerned with species composition diversity.

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